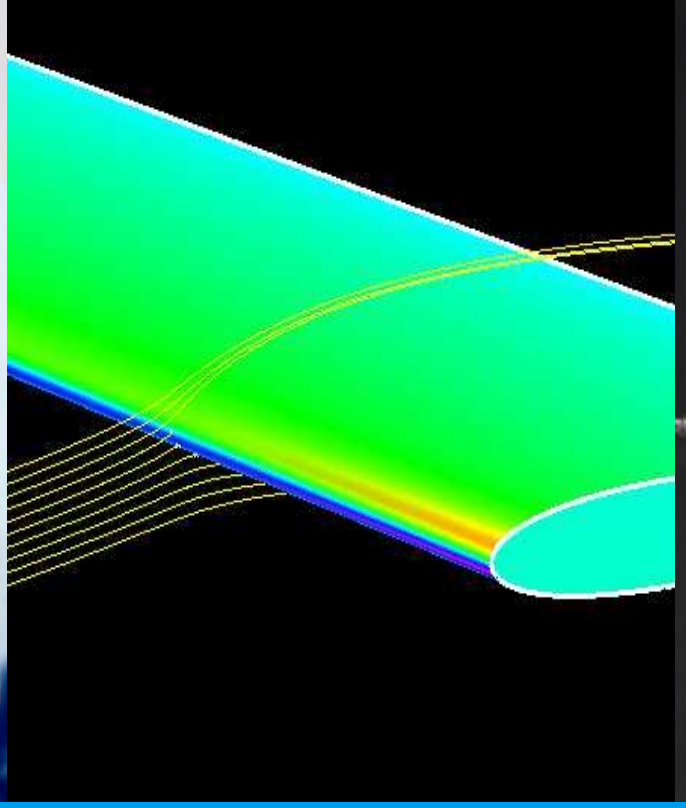
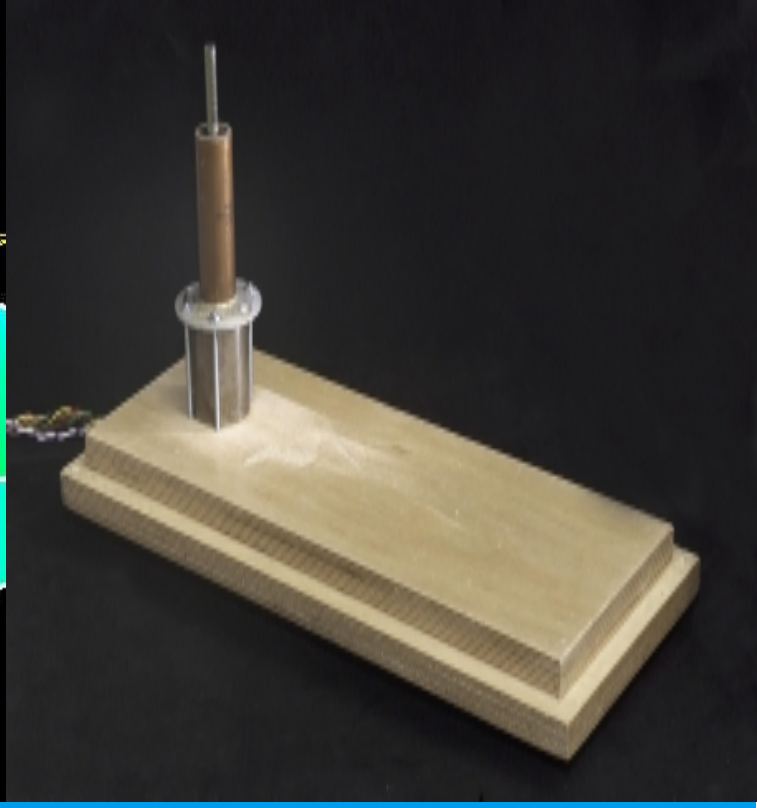
QinetiQ

SLD Research in the UK

Roger Gent, James Ford & Richard Moser - QinetiQ Ltd
Dean Miller - NASA Glenn

FAA In-flight Icing / Ground De-icing International Conference & Exhibition, June16-20, Chicago. IL. Paper 2003-01-2128

QinetiQ

Contents

- Introduction
- Overview of SLD Research
- Icing code developments
- Icing tunnel test campaigns
- Status of current activities
- Summary &conclusions
- Acknowledgements

QinetiQ

Introduction

- QinetiQ formed in July 2001
- National research agency privatised
  (QinetiQ DERA DRA RAE)
- Long history of icing research, especially analysis
- Developed TRAJICE2 (2D icing code)
- Partner in ICECREMO (3D icing code)
- Tools for ice protection systems and aero. performance degradation
- Military Aircraft Release, fixed-wing & rotorcraft

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Overview of SLD Research

- UK Agencies involved in SLD research:
  - QinetiQ (DERA)
  - BAE SYSTEMS
  - Airbus UK
  - Cranfield University
  - University College, London
- Activities coordinated under the ‘NOQ’ group
- Work to date includes
  - Icing code developments
  - IWT testing for code validation data
  - Splash investigations (Exp. & Theory)

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QinetiQ SLD Research

- Super-Cooled Large Droplet icing investigated since 1998
- Funded by UK civil government (DTI)

Icing Code developments

- Modified 2D icing code (TRAJICE2), drag law, gravity & splash
- Found poor prediction of ice shape - much larger than measured
- Reason attributed to inability to model splash mass loss

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QinetiQ SLD Research (2)

Icing Tunnel experiments

- Conducted 3 x SLD icing wind tunnel tests:
  - **ACT Artington 1998** (DERA)
    - Initial investigation + Ice shapes for code validation
  - **ACT Luton 2000** (DERA/BAE SYSTEMS) - SLD1
    - Splash investigation using high power laser imaging technique
    - Confirmed SLD splash
  - **ACT Luton 2002** (QinetiQ/NASA) - SLD2
    - Splash mass loss investigation

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QinetiQ Theoretical Study

TRAJICE2 Icing code development

- Code developed for JAR25 Appendix C + UK Military
- Code assumed:
  - Droplets remain spherical
  - Initial velocity = free-stream
  - Gravity effects small / ignored
  - No splash
- Code extended to include SLD icing
- Code modified such that:
  - Droplets can deform
  - Initial y velocity = terminal Vel.
  - Gravity effects included
  - Splash loss (=f(V, T))

- Impact limits OK
- Ice shape poor - too much ice!

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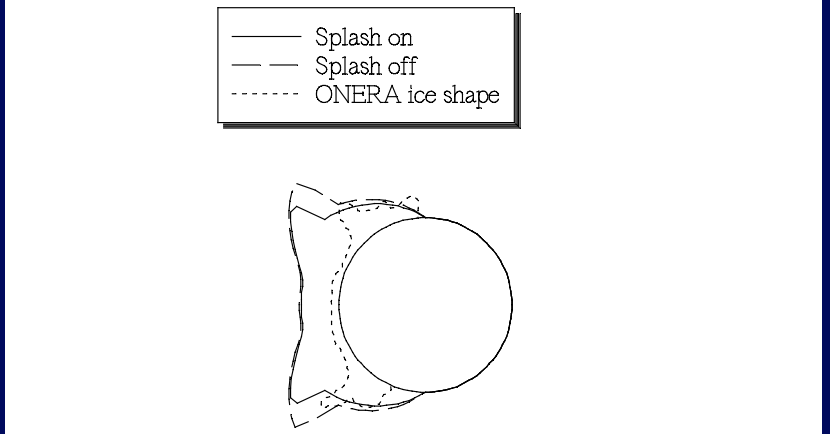
Evidence suggesting mass loss is important for SLD icing

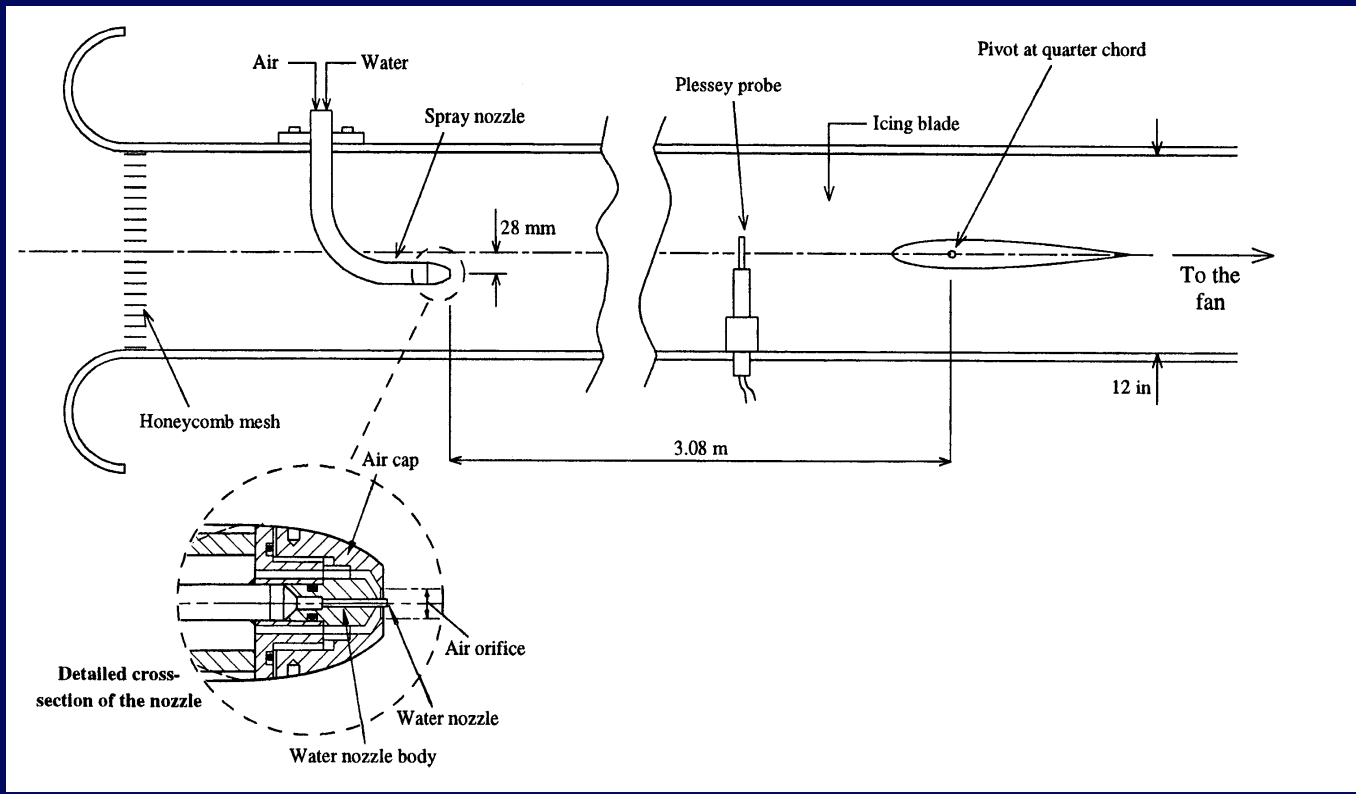


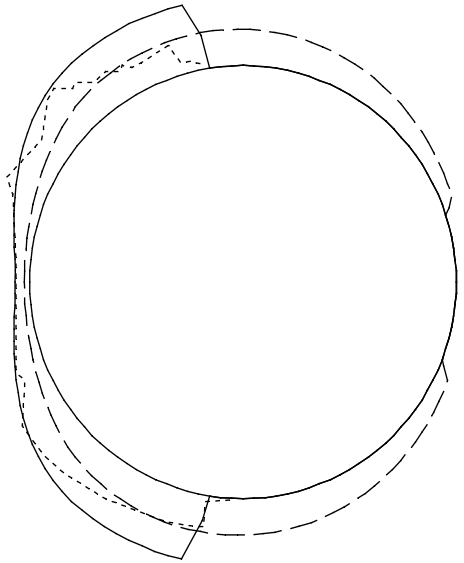
VMD=180μm, V=100 m/s, LWC=0.8 g/m^3

VMD=170μm, V=150 m/s, LWC=2 g/m^3

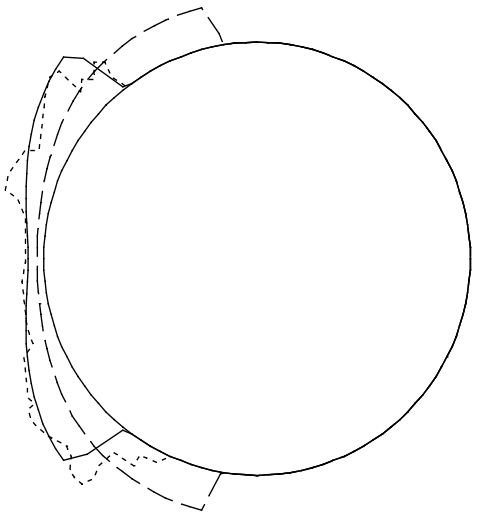
GKN-ACT Artington IRWT, 1998

- VMD~100μm
- LWC>1 g/m^3
- 2 x cylinders
- 6 inch NACA0012
- Ice shapes obtained
- RH < 100%
- Main conclusions
  - Measured ice shapes agree with prediction for Tt<-5C
  - RH effects on ice profile detected
  - Ice thickness over-predicted for Tt around freezing





SLD Cloud, RH=63%



Classical Cloud, RH=62%

Results showing the effect of RH on predicted ice shape

Predicted; Actual RH
Predicted; 100% RH
Measured profile

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GKN-ACT Luton IRWT, 2000 (SLD1)

- Funded by UK DTI. Included Collaboration with BAE SYSTEMS.
- Conducted at ACT Luton IRWT.
- Closed circuit tunnel.
- Droplet injection upstream of contraction.
- Working section 7” x 12”

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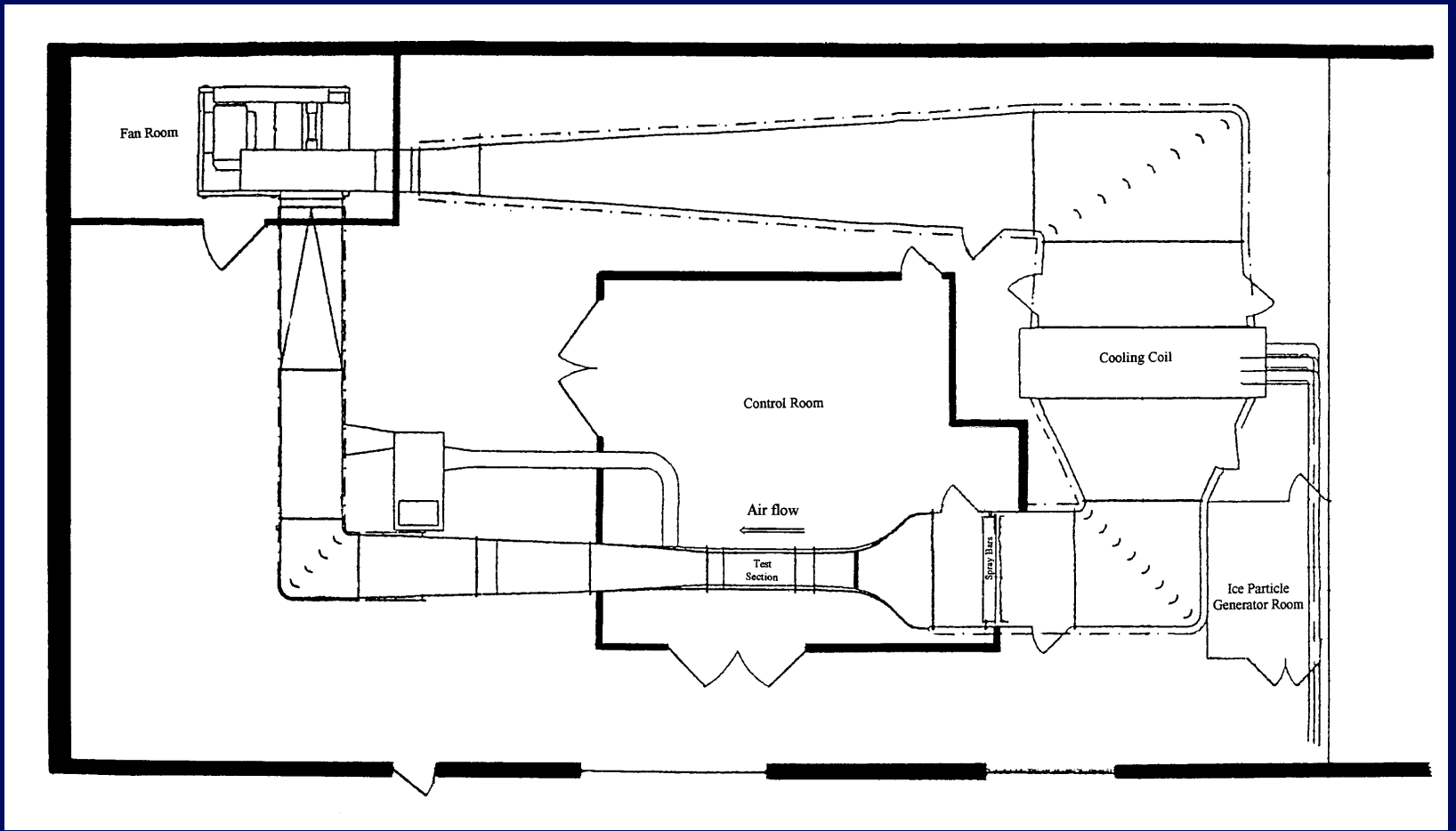
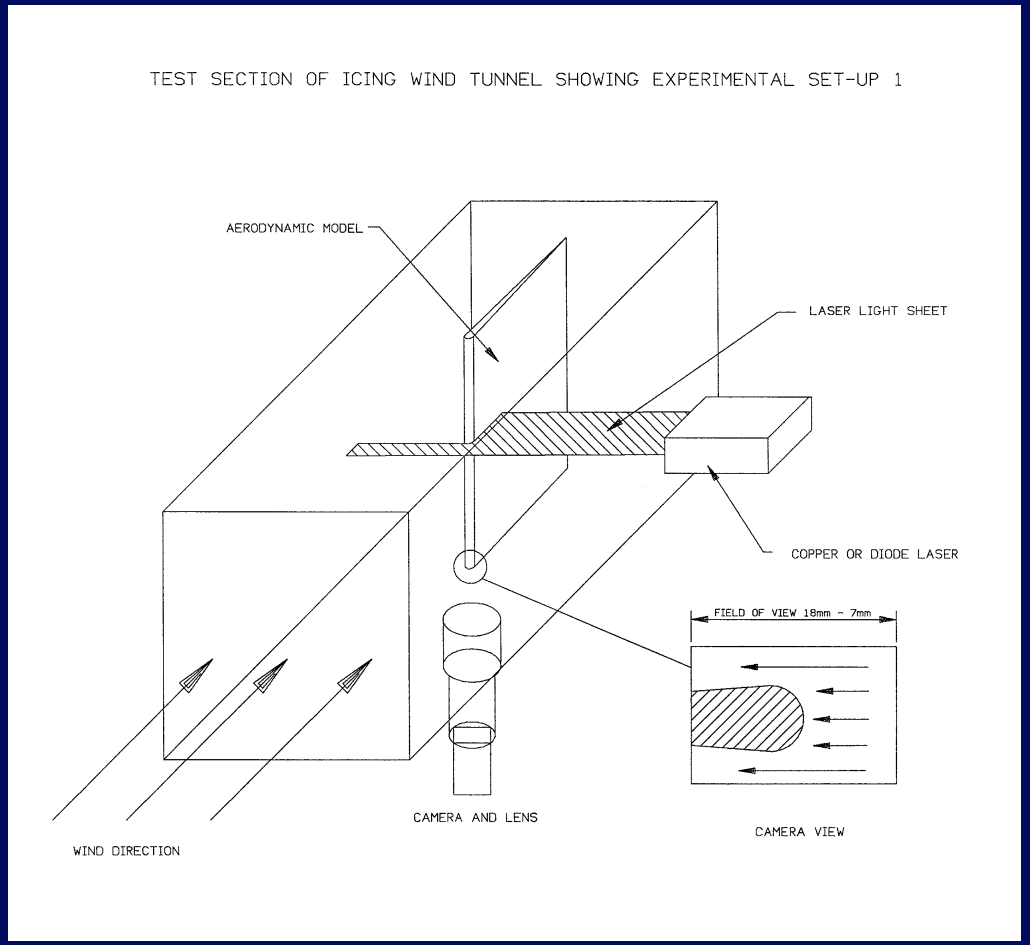
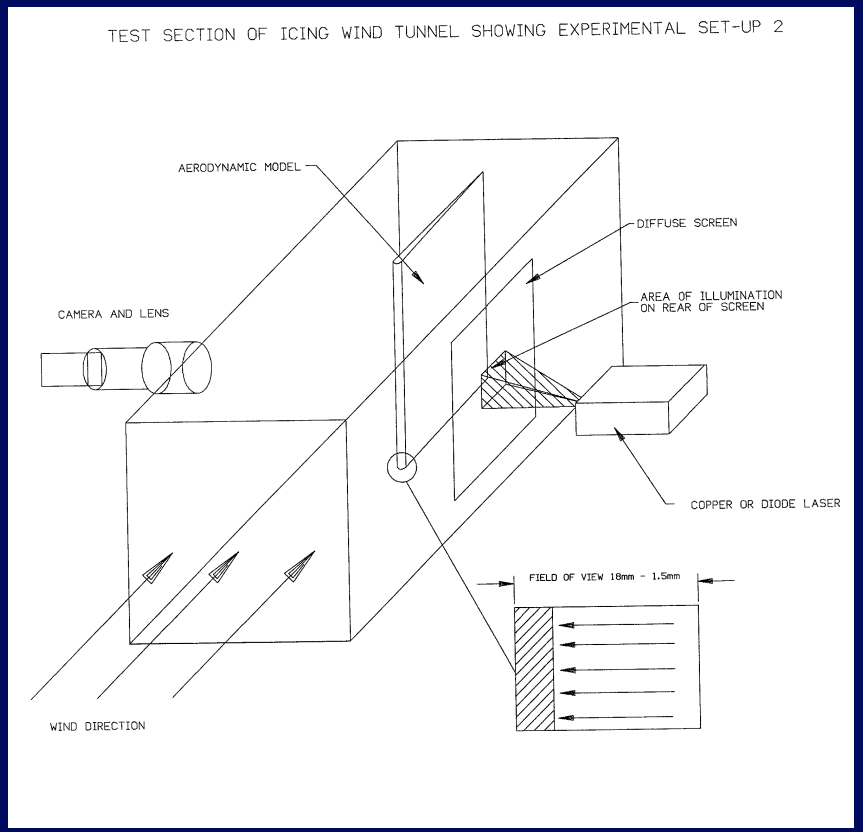
GKN-ACT Luton IRWT, 2000 (SLD1)

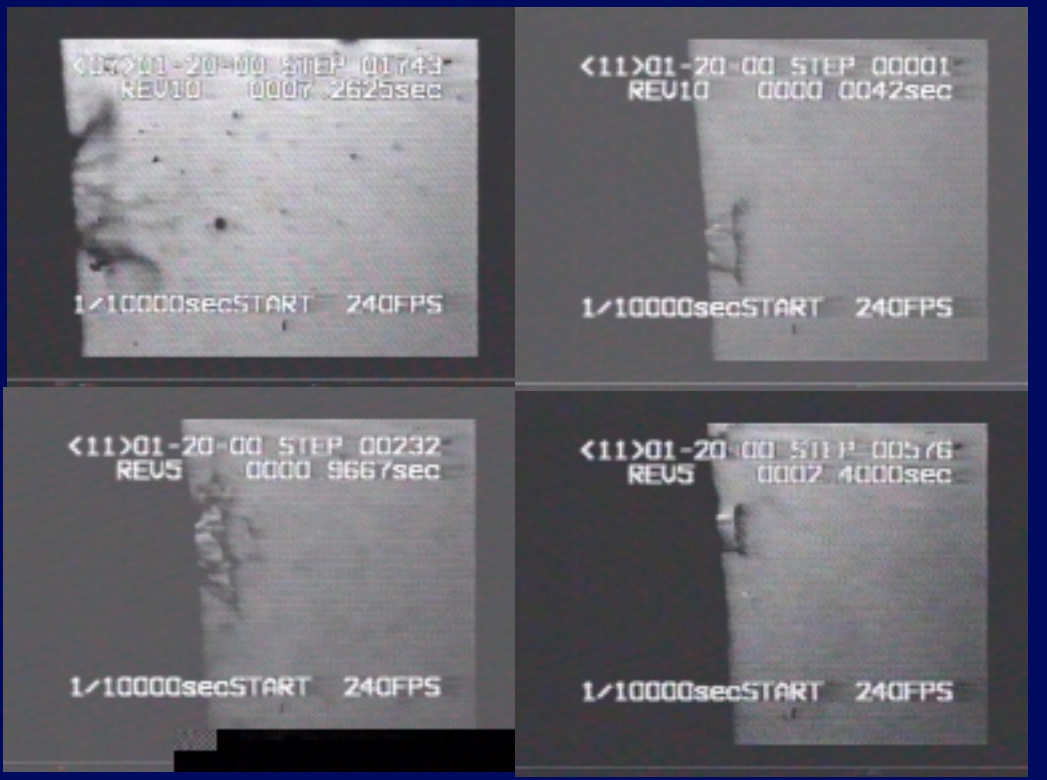


GKN-ACT Luton IRWT, 2000 (SLD1)

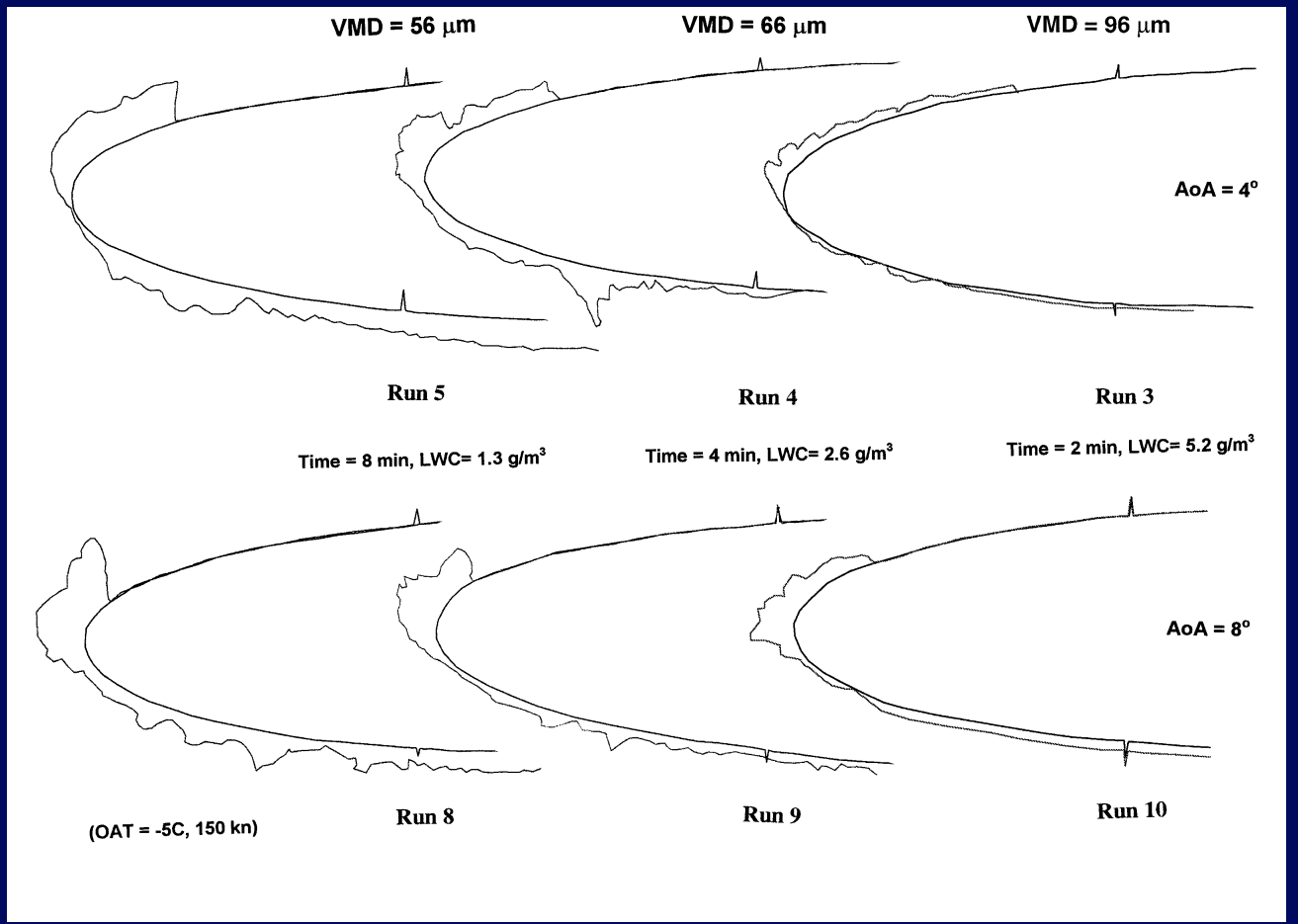


GKN-ACT Luton IRWT, 2000 (SLD1)





GKN-ACT Luton IRWT, 2000 (SLD1)



GKN-ACT Luton IRWT, 2002 (SLD2)

- Joint QinetiQ/Nasa trial
- Mass loss by direct measurement / Splash imaging
- Used 7 x 12 inch working section
- Measured mass loss via three methods
  - 1) Under-reading LWC probe
  - 2) Slotted ellipse (water film collection)
  - 3) Mass of accreted ice versus ideal mass
- Gathered additional ice shape validation data, cylinder and 6 inch chord NACA0012 wing

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GKN-ACT Luton IRWT, 2002 (SLD2)

- VMD of 50-200µm at LWC of 0.4 - ~1.0g/m^3
- Reduction in LWC of 500% from previous SLD test!
- Nominal 150 kn TAS, excursions to 100 kn and 200 kn
- OAT in range -10^{o}C to +15^{o}C

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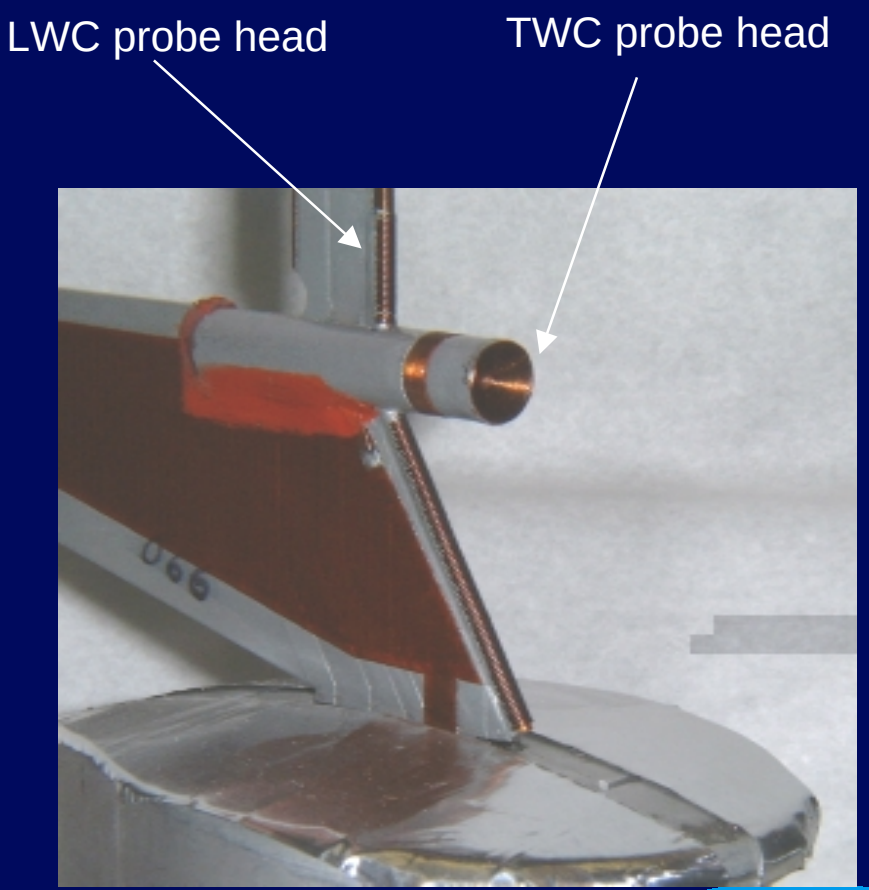
Under-reading LWC instrument (Nevzorov)

- Instrument has both TWC and LWC sensor heads
- Look at difference between measured TWC and LWC

- Originally intended to be tunnel ‘reference’ LWC in SLD
- Owned and operated by NASA



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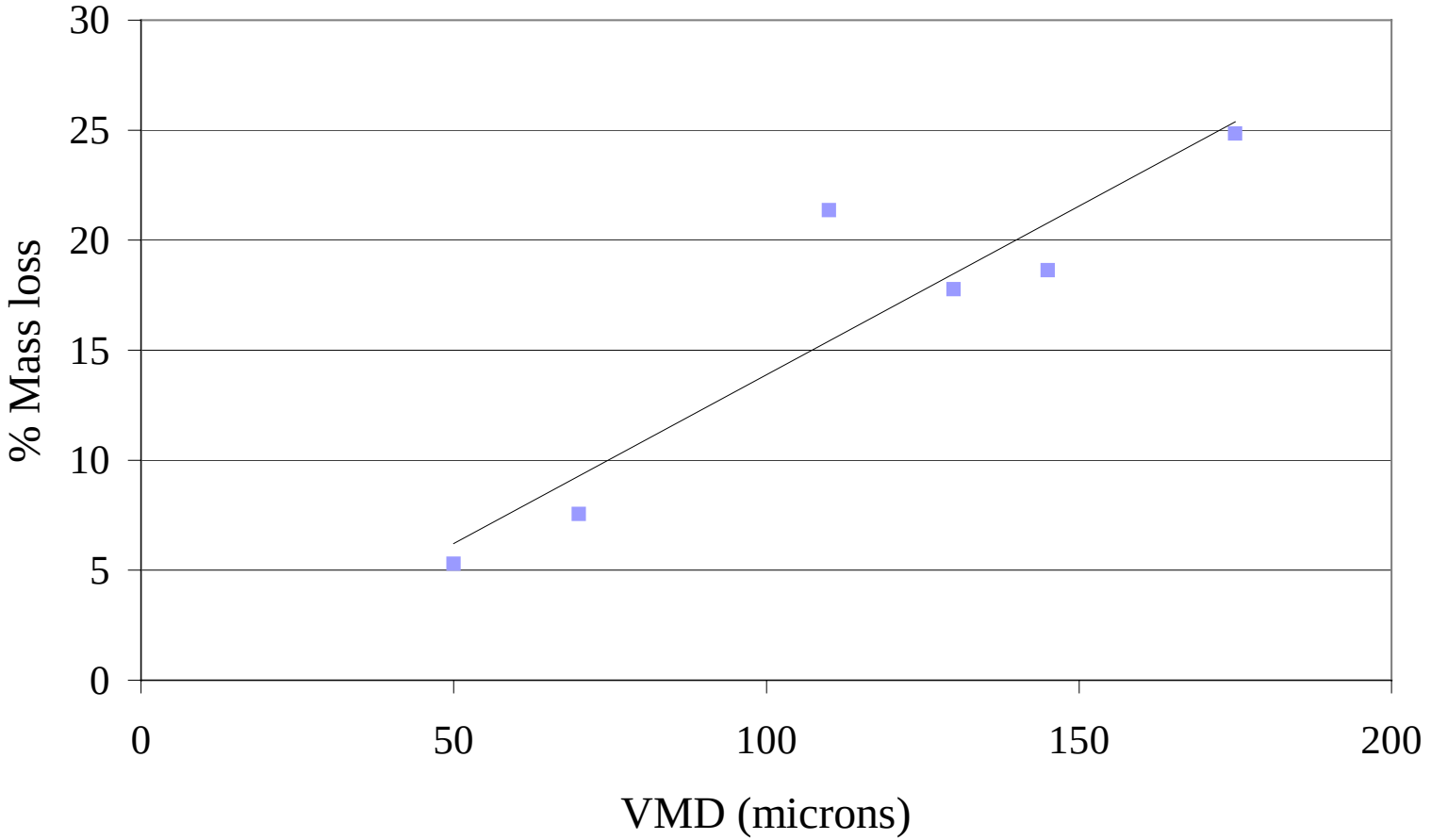
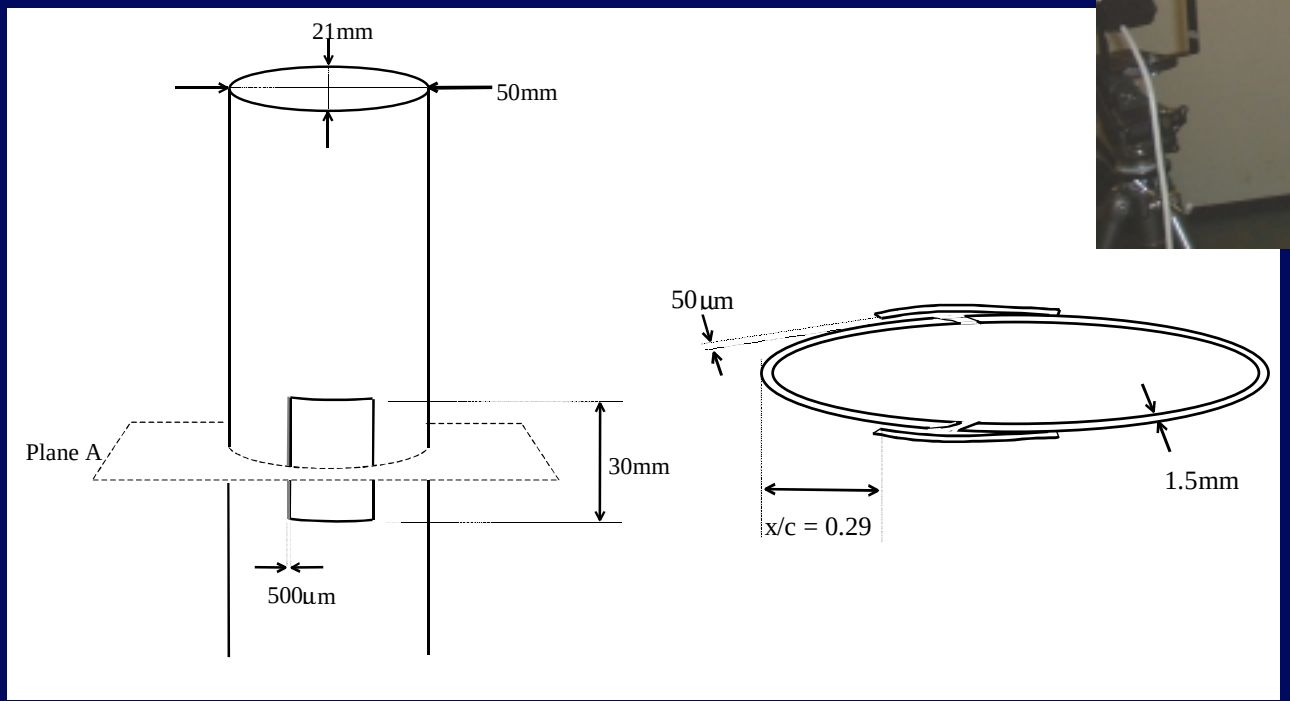
Results - Nevzorov TWC/LWC

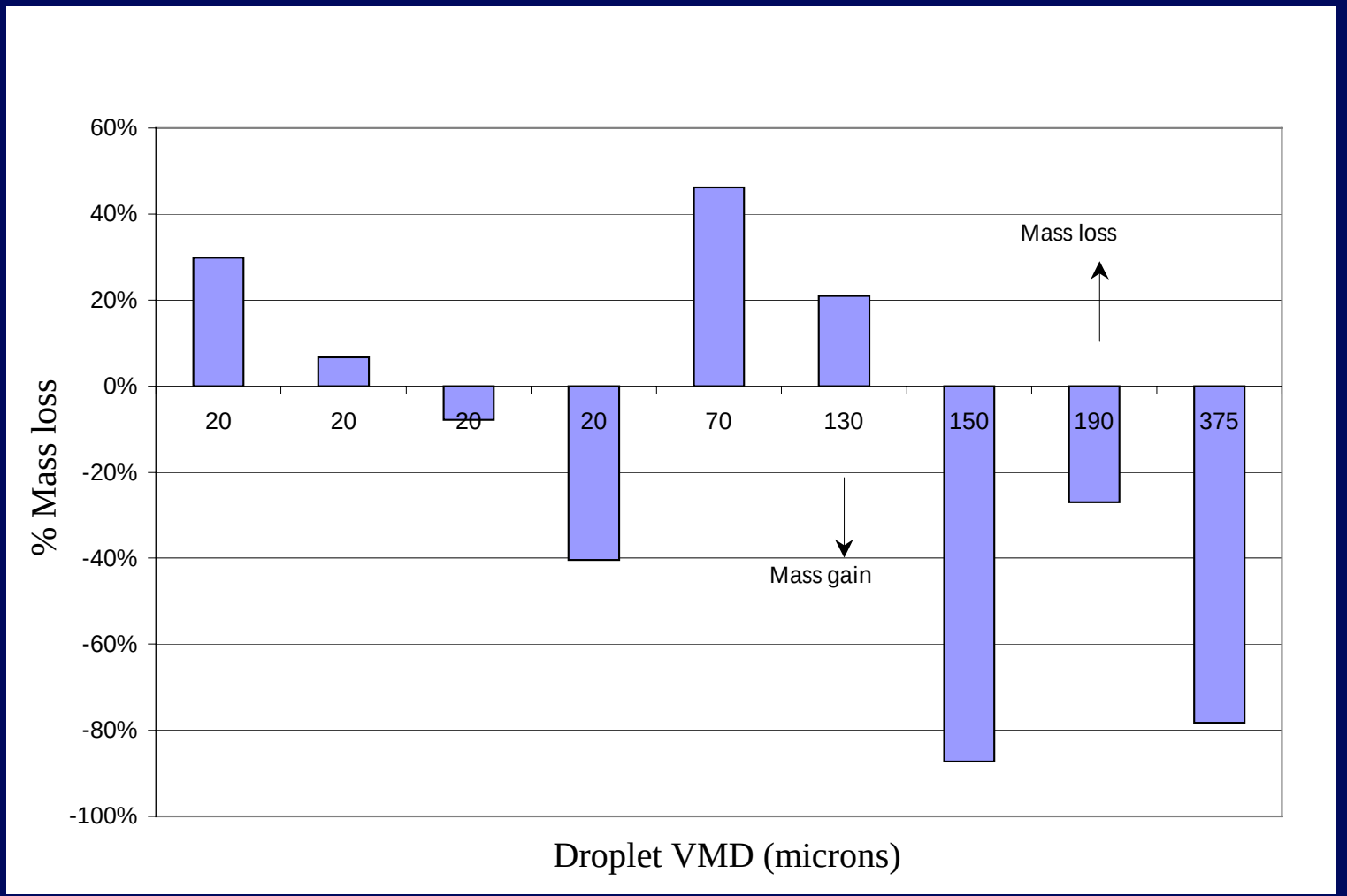


Slotted ellipse - Mass of retained water film

- Specimen had elliptical section
- Slot machined into each face
- Modified during trial



Results - Slotted Ellipse



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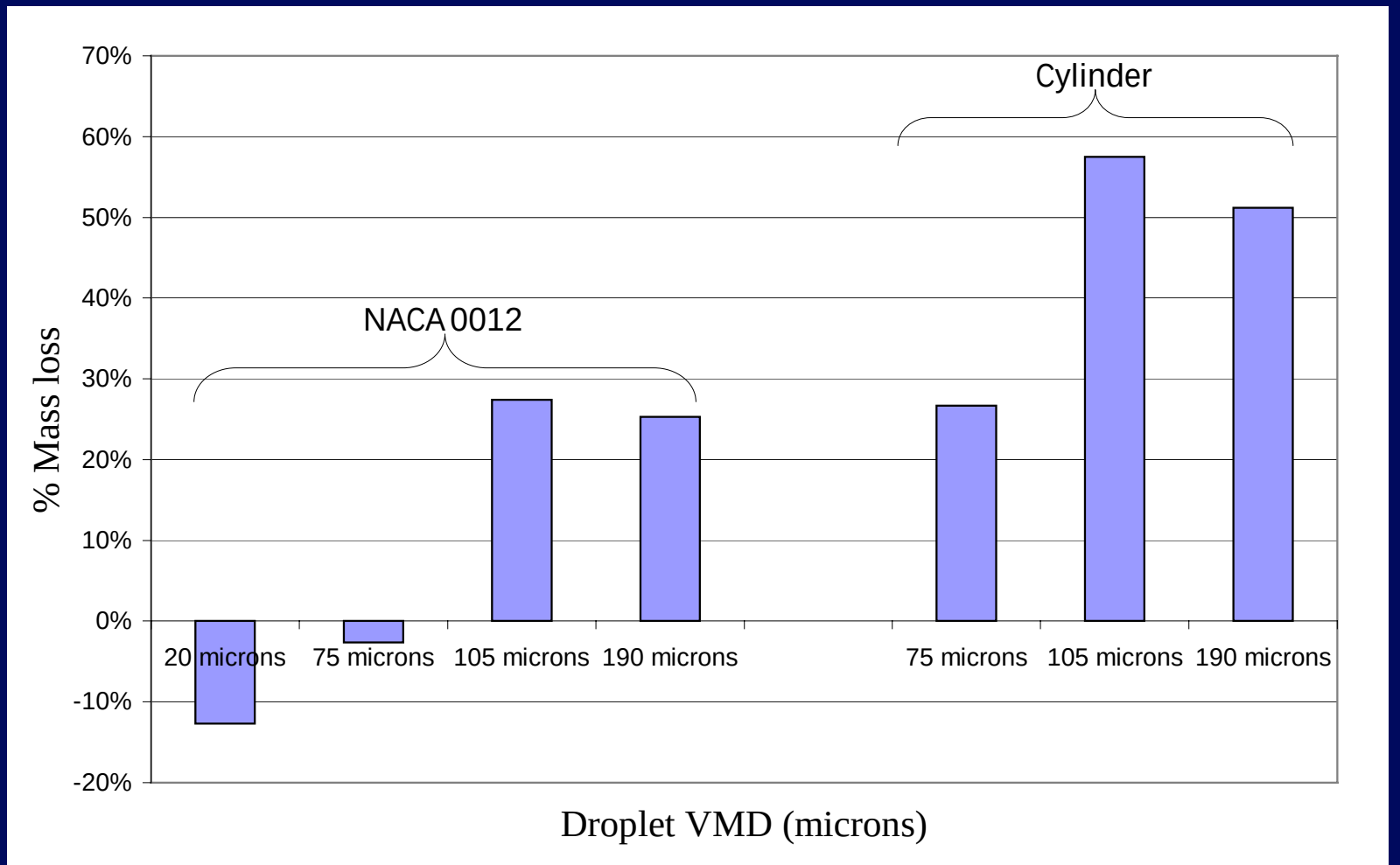
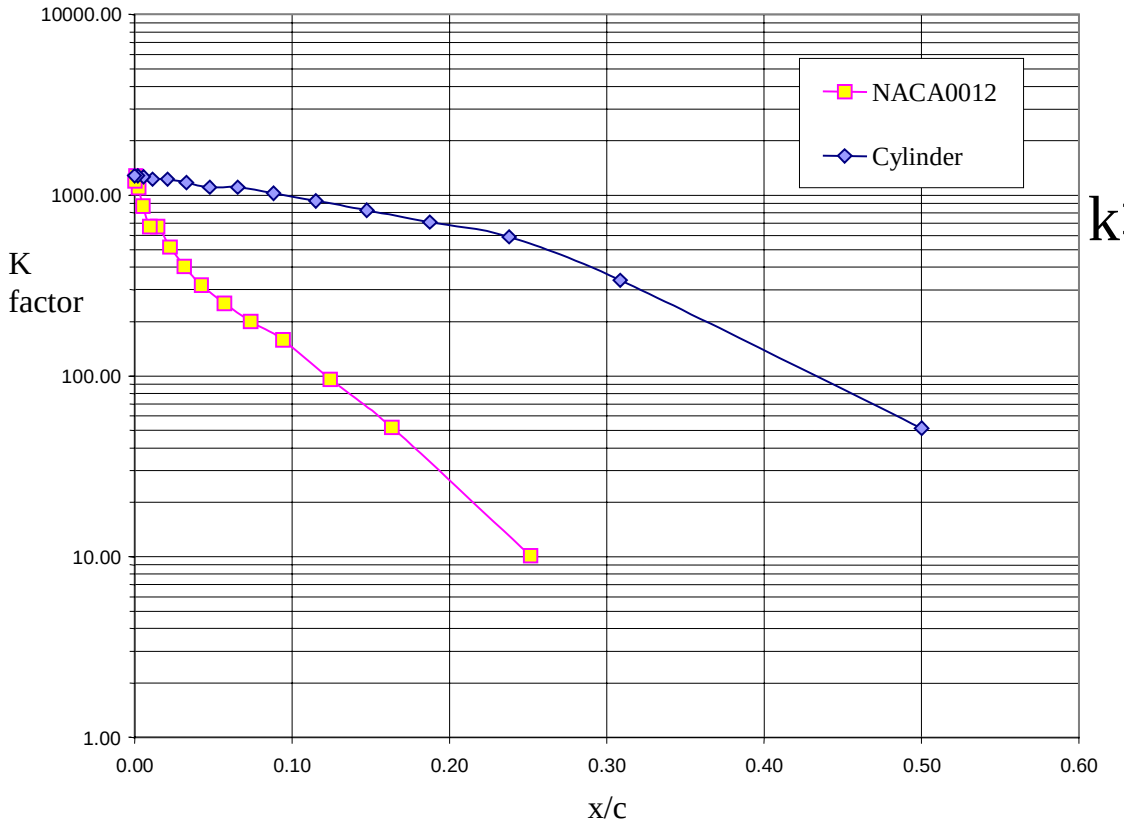
Method 3 - Mass of ice accreted

- Accrete ice on a specimen for given time
- Use heated saw to cut out section of ice
- Remove and weigh (melt water)
- Used two different specimens
  - 152 mm chord NACA0012 wing
  - 31 mm diameter alloy cylinder
- Compare weighed mass with predicted ‘ideal’ intercepted mass of water

Results - Ice accretion mass



Splash differences between aerofoil and cylinder



180 μm

k>70 for splash

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Conclusions from SLD2 trial

- For the specific conditions tested (<200 μm VMD, 150 kn)
  - Method 1 gave mass loss in range of +5% to +25%
  - Method 2 gave mass variation from +45% to -90% !
  - Method 3 gave mass loss in range
    - -10% to +30% on aerofoil specimen
    - up to +55% on cylinder, >> i.e. larger than aerofoil
- Shape of surface important to mass loss
- Reason for mass gain (Method 2) needs to be explained

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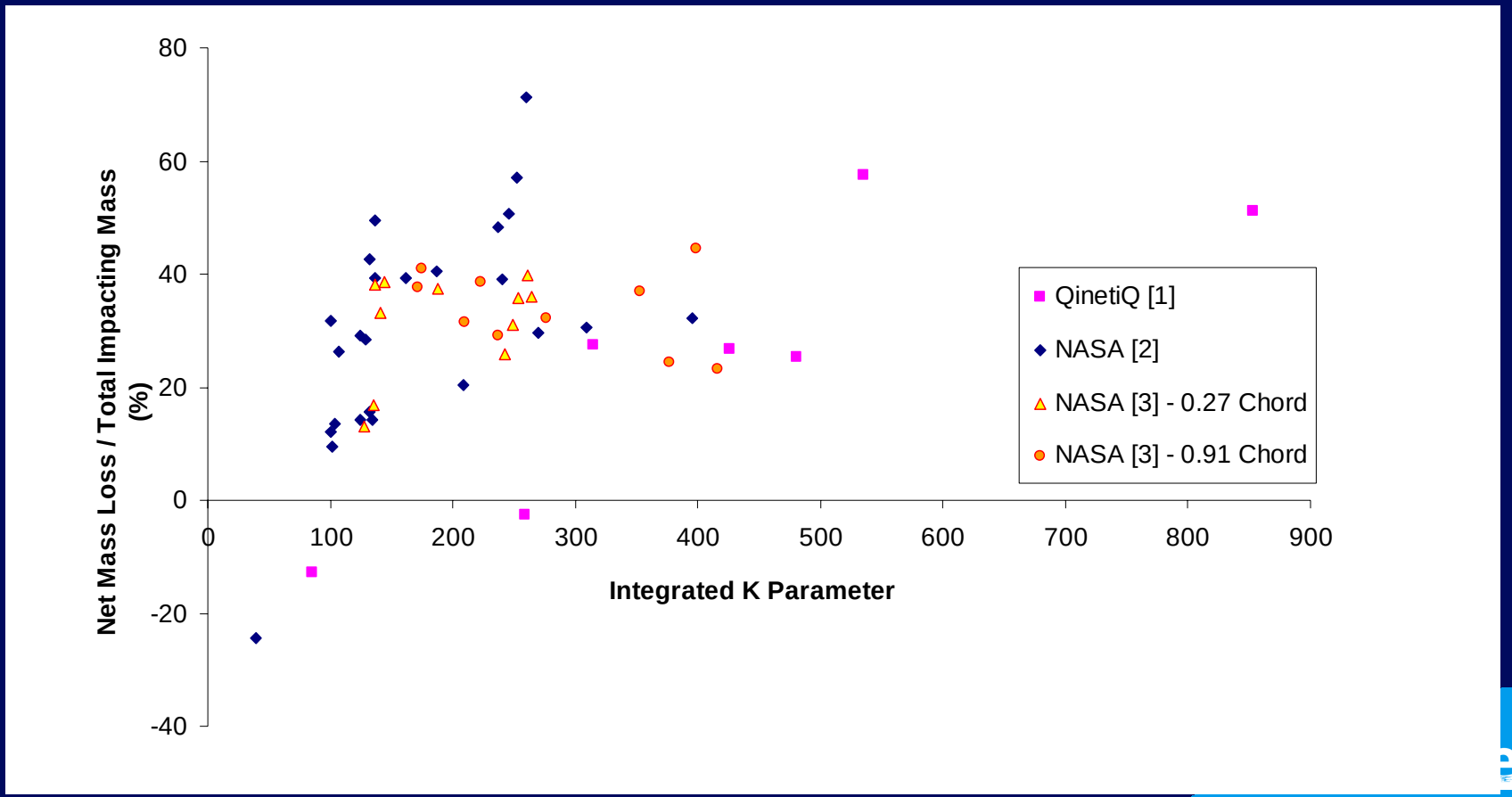
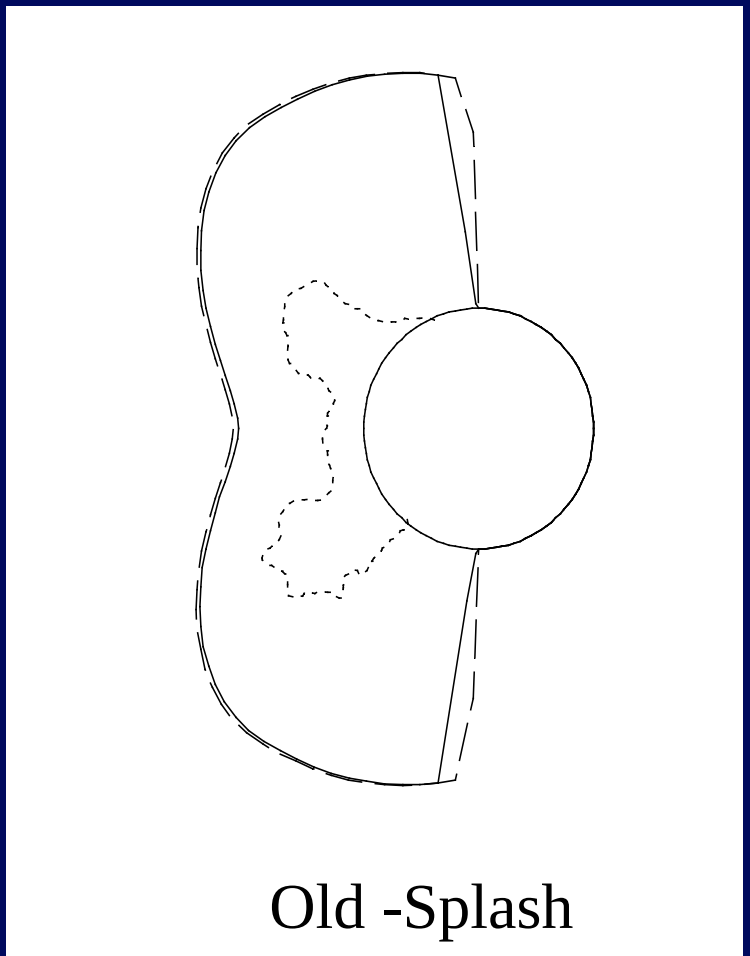
Status of current work - QinetiQ

- Converted ‘VMD’ data to integrated ‘K’ parameter
- Looking for correlation parameter(s)

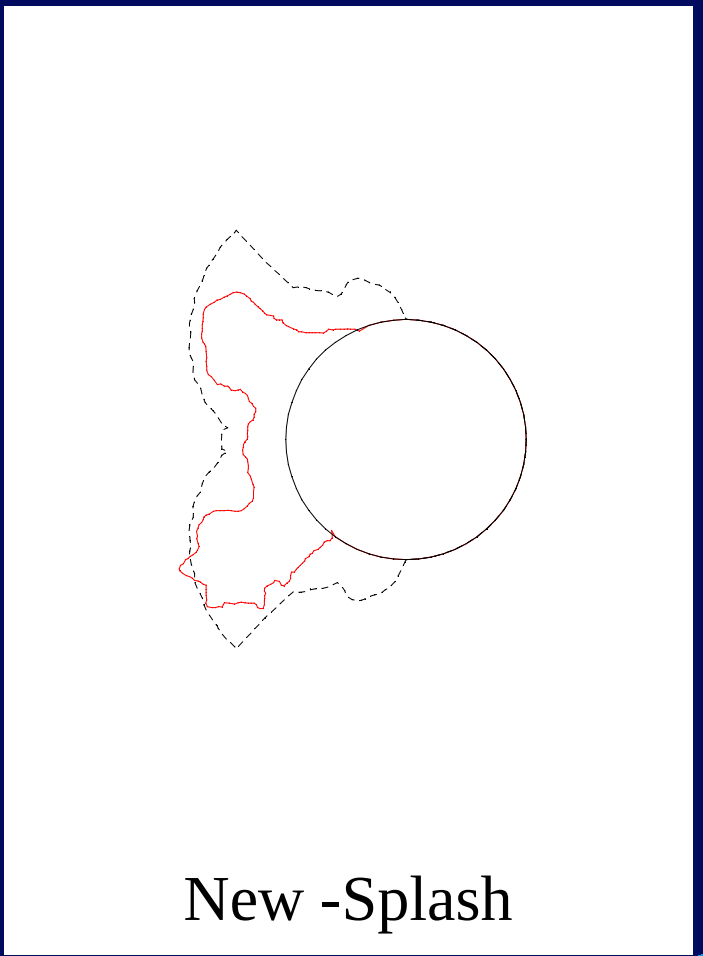


Evaluation of mass loss algorithm

(ONERA data)



Old -Splash



New -Splash

VMD=170µm, V=150 m/s, LWC=2 g/m^3

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Status of other UK Research - UCL

- University College London
- Maths Department (Prof Frank Smith, Dr Richard Purvis)
- 1st year of 3-year Post Graduate study ‘ Violent mechanics’
- Sponsored by Smiths Institute (EPSRC) and QinetiQ
- Theoretical study of water droplet into water film
- Volume of fluid method developed
- Using to investigate trends - droplet speed, diameter, water film height, ‘red and green’ fluid
- Currently includes surface tension
- Need to extend to include ambient velocity field / gravity
- Currently 2D model

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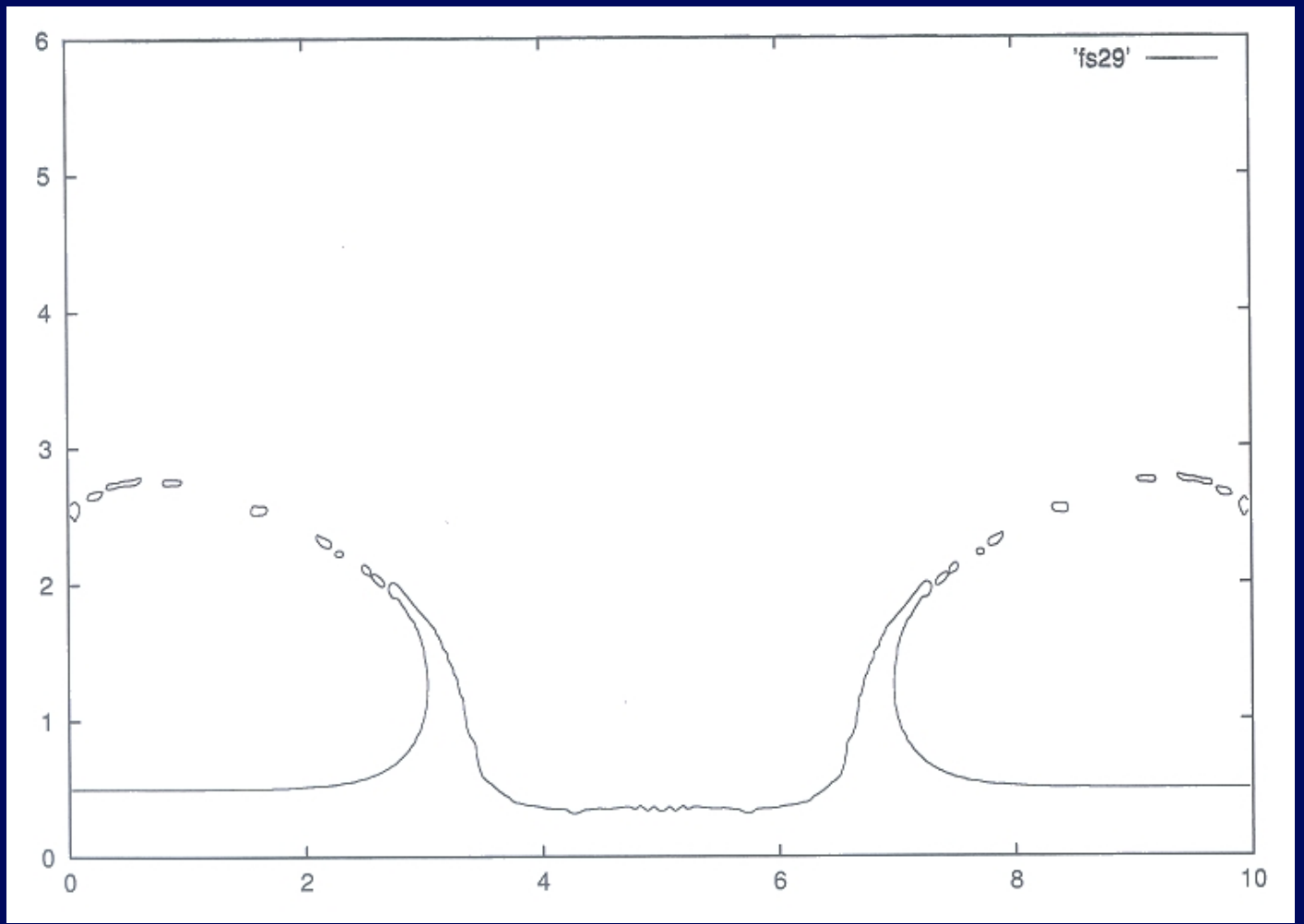
Status of other UK Research - UCL



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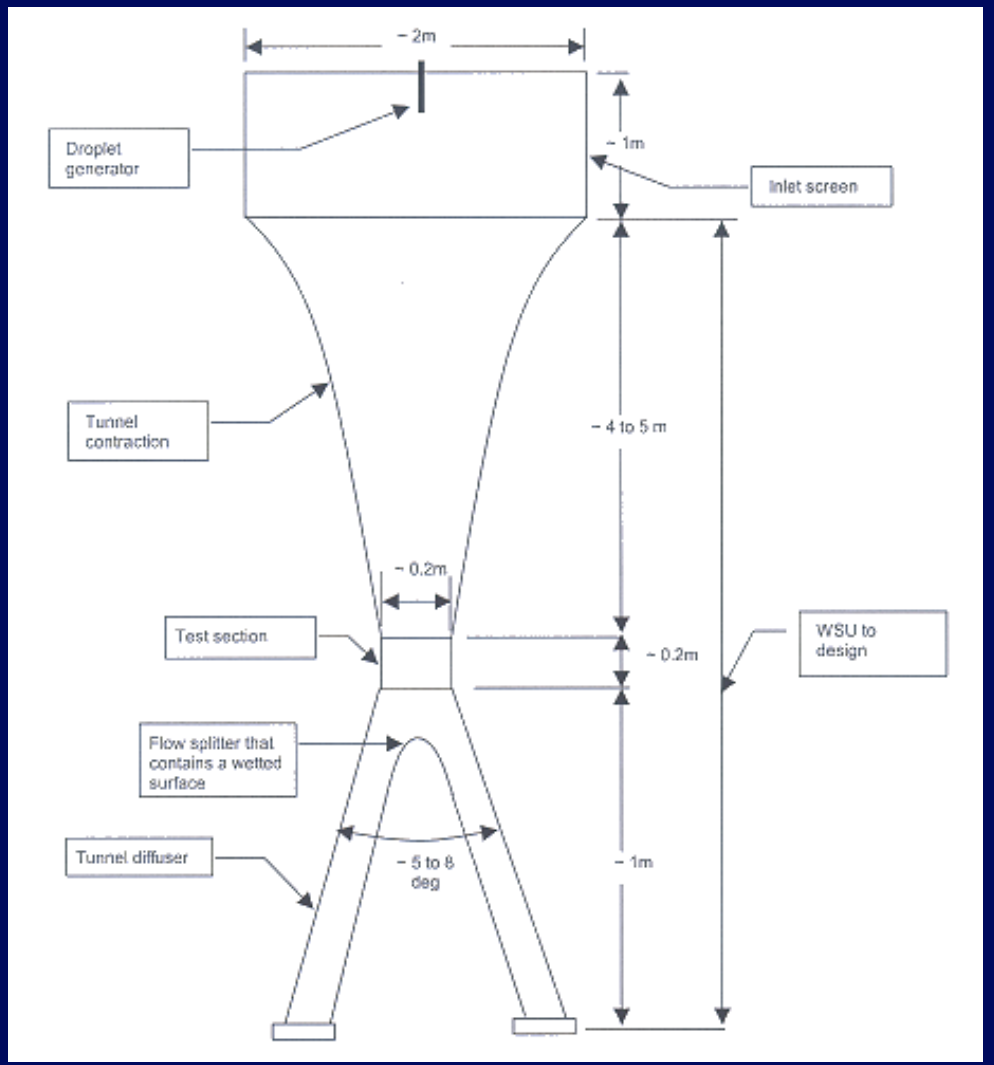
Status of other UK Research - Cranfield

- Sponsored by UK Civil Aviation Authority
- Lead Researcher - Dr David Hammond
- Experimental study of water droplets into water film
- New vertical wind tunnel to be used
- Tunnel uses main fan and cooling plant from Cranfield IRWT
- Most components built
- Initial testing imminent
- Will use various imaging and measurement techniques to quantify mass loss

QinetiQ

Status of other UK Research - Cranfield



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Summary and Conclusions

- UK research aimed at predicting SLD ice accretion
- Accretion code development, tunnel testing and fundamental Maths and Physics projects
- QinetiQ mass loss algorithm due for release by Feb 2004
- Cranfield results expected towards the end 2003
- UCL results helping to understand important mechanisms and are considering AIAA paper for 2004

- Activities will continue to be coordinated and reported within the NOQ Group (SLD Methods development)

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Acknowledgements

- This work was sponsored by the UK Department of Trade & Industry under the Aerospace Research Programme

- Special thanks to Glenn Howard and Berni Bardwell of the ACT Luton IRWT, for their assistance during the SLD testing

- Sincere thanks to NASA Glenn and to the FAA for supporting the joint QinetiQ/NASA trial, ACT Luton, May 2002

QinetiQ